Mycenaean ‘Alum’:
Implications for the Exchange of Astringent Minerals in the Bronze Age

Effie Photos-Jones * - *Richard Jones* *

Summary: This paper is speculative but is based on the observation that there is archaeological evidence for the existence of Mycenaean pottery in the vicinity of natural resources, rich in astringent minerals. These resources include alum group minerals from the volcanic environments of Melos, in the Aegean, the Aeolian Islands and the Bay of Naples in Italy and the metal sulphates of Cyprus associated with copper sulphide mineralisation. Both types of minerals could have served (amongst other applications) as mordants for the Bronze Age textiles industry. Despite Mycenaean awareness of these minerals, there is little evidence for Mycenaean trading in them. There is however the interesting reference in the Linear B tablets to *tu-ru-pte-ri-ja*, *stypteria*, or alum. We suggest that the term may have covered all types of astringent minerals, from both east and west, particularly in view of its association in one tablet from Pylos, with *ku-pi-ri-jo*, *Kuprios* or Cypriot. The proposal has implications for the Bronze Age minerals exploration and exchange which goes, currently, ‘under the radar’.

Key words: alum, astringency, Melos, Aeolian Islands, Bay of Naples, Cyprus, Mycenaean, copper sulphates.

Introduction

During the Aegean Bronze Age (BA) and especially the Late Bronze Age (LBA) the documentary sources (Linear B tablets) and two Pylos tablets, in particular, make reference to the term *tu-ru-pte-ri-ja* which has been translated as alum (or potassium alum) (Firth 2007; Perna 2005; Chadwick 1976, 157). In this paper we argue that this term should perhaps be treated as a generic term to refer to many and diverse astringent minerals across the Mediterranean, rather than *only* potassium alum. This is on account of the evidence for Mycenaean pottery in localities, across the Mediterranean (Fig. 1) and in the proximity of diverse astringent minerals. This proposal points to the fact that it is likely that, once in these localities, Mycenaeans would have been aware of these diverse and colourful minerals (Table 1) and may have referred to them collectively on the grounds of the one distinct property that was shared by all, namely astringency.

Astringency has at least two different meanings: it is a gustatory sensation, namely the puckering of the mouth, which was well recognised in Roman period (Pliny *Natural History*, 35.52; Dioscorides *De Materia Medica* V). The second is a medical one: astringent substances are those that *‘cause the contraction or shrinkage of tissues and dry up secretions’.* The ‘stemming of the flow of blood’ was also well recognised by the Roman period. Dioscorides lists many astringent minerals, of which the alum group minerals is only one. Sources include the natural alum (solphataric) and alunite-based deposits of Melos, the Aeolian Islands and the Bay of Naples, Italy (Fig.1).

In addition to the alum group minerals, Dioscorides also lists metal-based astringent minerals, which derive largely from the extraction and processing of metalliferous ores (copper/iron/zinc) but also from

* University of Glasgow.
It is a pleasure to offer this contribution to the present volume, as it draws, if only in a small way, on early Mycenaean presence in Italy as seen through the ceramic evidence, whose study Lucia Vagnetti pioneered in the Central Mediterranean as a whole, together with the newer, multidisciplinary investigation of antimicrobial minerals in (ancient) Greece and Italy developed by the first author and her collaborators. We thank the editors of this volume for the invitation to contribute and for their considerable patience.

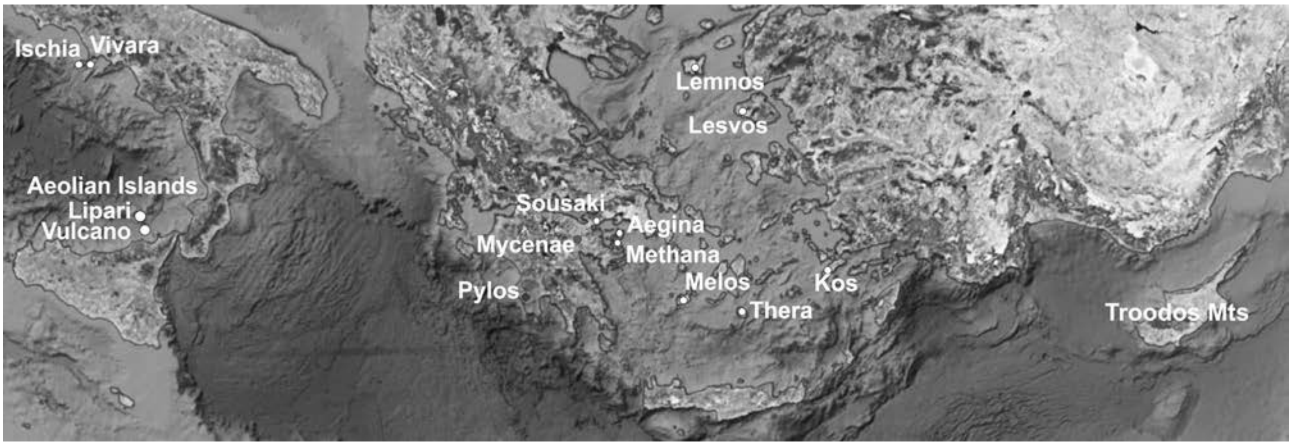

Fig. 1. Map showing sites and locations in Italy, the Aegean and Cyprus mentioned in the text.

workshop practices, some of them difficult to characterise mineralogically today. During the Roman period and perhaps earlier, one important source of metal-based astringents was Cyprus and in particular the metal sulphates associated with the weathering of the large copper sulphide deposits of the Troodos range (Fig. 1). These mines were visited in the 2nd c AD by Galen who was interested in mineral remedies rather than smelted copper ore (Wallace, Orphanides 1990).

Regarding applications, soluble astringent minerals would have been used as mordants in textiles (Nosch 2014, 8) and in tanning (see Rifkin 2011 for any period). We report on the medicinal properties of the alum group minerals as antibacterials (Photos-Jones et al 2016) and even hemostatics, a property acknowledged from at least the mid-2nd millennium BC in the Egyptian Ebers papyrus (*c.* 1550 BC). In addressing the alum group minerals and their various applications, it is important to appreciate the role of solubility. Not all astringent minerals are soluble, an essential property in mordants, but non-soluble astringent minerals could have been used in other applications (Singer 1948).

This paper investigates the archaeological evidence for Mycenaeans' *potential* contact with, on the one hand, the sources of solphataric alum in Greece and Italy and, on the other, the metallic sulphate minerals in Cyprus; this is done by tracing the appearance of Mycenaean pottery as an indicator of Mycenaean presence in close proximity to those sources. Where there is a coincidence of astringent mineral and Mycenaean presence, and the closer the pottery to the source the better, there is the possibility, usually no more, that that source could have been known and/or exploited at that time either by the indigenous population and/or exchanged with 'visitors' to the island. Apart from the sources mentioned above, smaller much less known ones yet with evidence of Mycenaean presence (Aegina, Corinthia, Lemnos, Lesvos), are also discussed.

Melos
Alum from solphataric landscapes

Alum-group minerals derive from volcanic landscapes but not all volcanic landscapes are active. Amongst the latter are the solphataric landscapes. Solphataras are fields with fumaroles, namely hydrothermal vents emitting steam and noxious gases like carbon and sulphur dioxides. Wherever they occur, solphataric landscapes are remarkable, even by today's standards, in view of the impact they have on the senses of smell, taste and vision. They would hardly have gone unnoticed in the BA. Solphataric alum derives from aluminium and sulphates dissolved into the water rising as steam from the earth's interior. Upon reaching the surface the dissolved minerals form fine (fluffy) efflorescences of alunogen and alum(-K) or potassium alum (Table 1 and Fig. 2a). Fine yellow crystals of sulphur, also dissolved in the steam, form as well in the vicinity of the alum minerals upon arriving at ground surface. Both crystals of yellow and white minerals would be visible one next to the other as in Fig. 2a. The Melos alum group minerals were well known to Pliny who makes reference to their different varieties as well as the places of

Campi Flegrei, Naples and Melos (adapted from Photos-Jones et al 2016, Table 1)		
Alum-(K)	$KAl(SO_4)_2 \cdot 12H_2O$	White
Alunite	$KAl_3(SO_4)_2(OH)_6$	White
Alunogen	$Al_2(SO_4)_3 \cdot 17H_2O$	White
Anhydrite	$CaSO_4$	Colourless to pale blue
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$	Colourless to yellow
Gypsum	$CaSO_4 \cdot 2H_2O$	Colourless-white
Hydrobasaluminite	$Al_4(SO_4)(OH)_{10} \cdot 12\text{-}36H_2O$	White
Millosevichite	$Al_2(SO_4)_3$	Red
Steklite	$KAl(SO_4)_2$	Colourless-white
Sulphur	S	Yellow
Tschermigite	$(NH_4)Al(SO_4)_2 \cdot 12H_2O$	Colourless
Vulcano: sulphate minerals (after Photos-Jones et al 2018)		
Alunite	$KAl_3(SO_4)_2(OH)_6$	White
Gypsum	$CaSO_4 \cdot 2H_2O$	White
Sulphur	S	Yellow
Alunogen	$Al_2(SO_4)_3 \cdot 17H_2O$	White
Tamarurgite	$NaAl(SO_4)_2 \cdot 6H_2O$	Colourless
Alum-(K)	$KAl(SO_4)_2 \cdot 12H_2O$	White
Voltaite	$K_2Fe^{2+}{}_5Fe^{3+}{}_3Al(SO_4)_{12} \cdot 18H_2O$	Green to greenish-black
Pickeringite	$MgAl_2(SO_4)_4 \cdot 22H_2O$	Colourless- white
Halotricite	$FeAl_2(SO_4)_4 \cdot 22H_2O$	Colourless- white
Troodos Range, Cyprus: iron/copper sulphate minerals (vitriols) from copper sulphide oxidation (after Koucky and Steinberg 1989, Table 4)		
Misy:	$Fe_5(SO_4)_6(OH)_2.20H_2O$	Pale-bright yellow
Copiapite	$(K, Na, Fe)_5(Fe_3SO_4)_6 (OH).7H_2O$	yellow
Metavoltine		
Chalcitis	$(Fe,Cu)_3(SO_4)_4.14H_2O$ with	Pale reddish-brown
Romerite	$(Fe,Cu,Zn)SO_4.7H_2O$	Light to dark orange-red
Botryogen	$MgFe(O_4)_2(OH).7H_2O$	
Sory	$(Fe,Cu)SO_4.7H_2O$	Colourless to white or green, also greenish-blue to blue
Melanterite	FeS2	Yellowish grey to grey
fine pyrite		
Melanteria *Melanterite*	$(Fe,Cu)SO_4.7H_2O$	Colourless to white or green, also greenish-blue to blue
Atramentum: sutorium caerteum chalcanthite	$CuSO_4.5H_2O$	Blue-green
Atramentum: sutorium candidum goslarite	$ZnSO_4.7H_2O$	Variable but often white
Atramentum: sutorium virida melanterite	$(Fe,Cu)SO_4.7H_2O$	Colourless to white or green, also greenish-blue to blue

Table 1. Aluminium and other sulphate minerals, their chemical formula and colour (obtained from mindat.org).

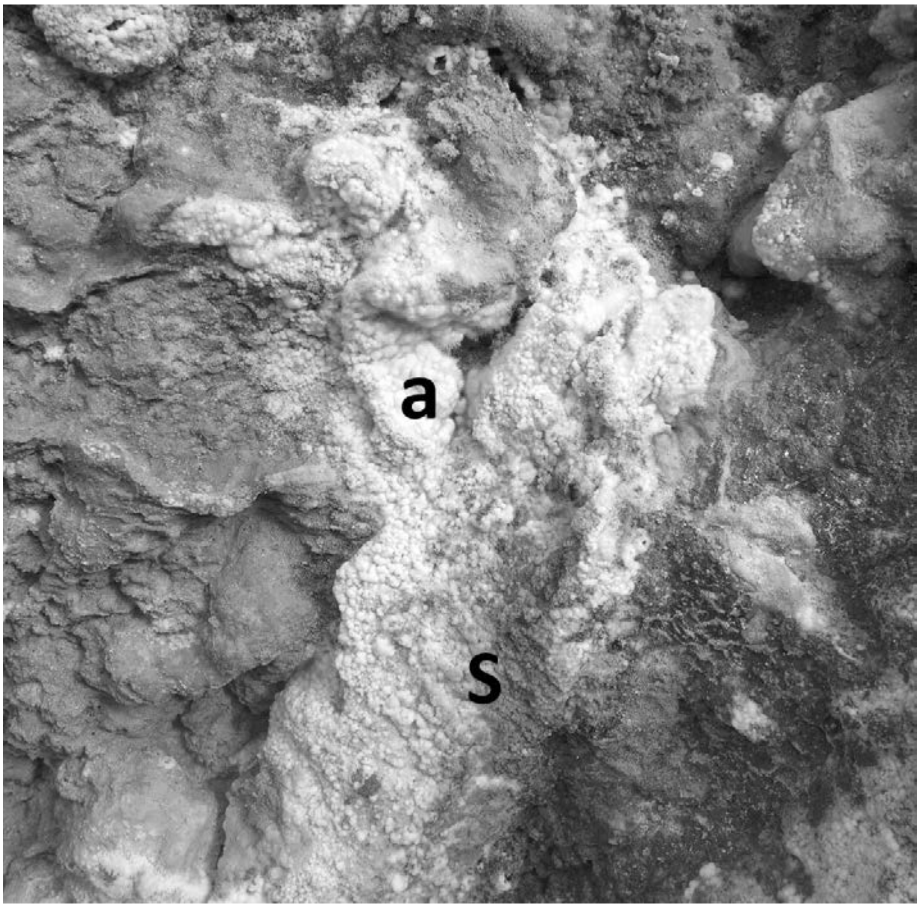

Fig. 2a Solphataric alum efflorescences ((a) and white) in the immediate vicinity of crystals of sulphur ((s) and yellow).
Field of view is 5cm across. Origin: Vulcano, Aeolian Islands, Italy.

Fig. 2b Alunite/kaolinite and associated minerals quarry face in Loulos, SE Melos.
One of our colleagues (see arrow) is looking into the opening of one of the ancient tunnels, his body used here for scale.
The quarry face is over 20m high (after Photos-Jones, Hall 2014, fig. 8.33c).

origin.[1] We have argued that Pliny's description of Melian alum (*Natural History* 35.52) as *liquid*, *milky white* and *warm* is an accurate depiction of what would have been a rich source of solphataric alum in the Roman period in Melos (Photos-Jones, Hall 2010; Photos-Jones, Hall 2014, 52).

While the above alum group minerals are soluble, alunite (with or without other minerals) (Table 1) is not. Alunite is often equated with 'alum stone'. The latter was the source of alum in Egypt in the 5th century BC (Herodotus *Histories* 2.180) and Mesopotamian texts also referred to alum as alum stone (*aban*) (Levey 1958, 166). Sumerian texts allude to alum as 'powder of stone of the mountain' or 'powder of alum' (Levey 1958, 167). 'Powder' can mean either pulverised rock or '*a shale from which alum may be derived*', which Levey suggests was the case, but unless one has knowledge of the local sources and evidence of their exploitation during the period in question it is not possible to be certain. Matoian and Vita (2014) and Postgate (2014) mention alum in the Ugaritic and mid-Assyrian texts respectively, which are roughly contemporaneous with the Mycenaean sources. Thus, although there are many references to alum in early texts, there is relatively little understanding of the type of alum involved, let alone whether it was processed, how it travelled and how widely it was exchanged. Since solubility affects applications, it is important when discussing alum to know the type of alum and for which application it may have been intended.

The production of soluble potassium alum from insoluble alunite rock[2] is archaeologically documented from the middle of the first millennium AD. For example, there is archaeological evidence in the form of kilns for the processing of the alunite in 7th century AD Lesvos (Archontidou 2005). On Melos, the alunite, kaolinite and silica mineral combination from at least one particular deposit (Loulos in the S.E. of the island (Figs. 2b and 3) must have formed one of the sources of the renowned 'Melian Earth', a white pigment known to Pliny as *melinum* (*Natural History* 35.52) (Photos-Jones, Hall 2014, 50). There is (thus far) no concrete evidence for alum-roasting kilns on Melos. This suggests that Roman Melos was exploiting both soluble and insoluble alum deposits which it directed to its various industries: on the one hand, 'Melian Earth' or *melinum* for pigments and perhaps hemostatics as well, on the other, solphataric alum deposits for mordanting and tanning. This is the view from Roman Melos, so far (Photos-Jones 2018).

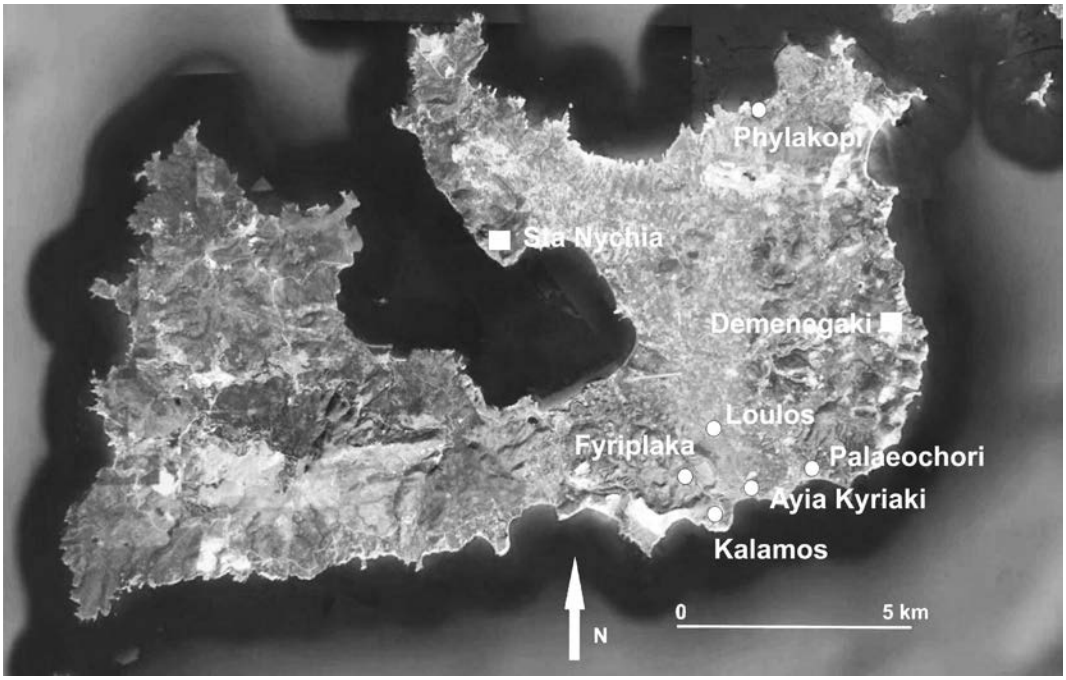

Fig. 3. Map showing locations and sites on Melos mentioned in the text; obsidian sources are marked with a square.

[1] There are 34 entries in *Natural History*, see http://www.perseus.tufts.edu/hopper/searchresults?target=en&inContent=true&q=alum&doc=Perseus%3Atext%3A1999.02.0137

[2] The process involved first the roasting of alunite in kilns and the subsequent immersion of the roasted mineral in water leading to the formation of the hydrated potassium alum. For formulas see Table 1.

A major problem in the pursuit of alum in the archaeological record is that it is largely 'invisible'. Although there are certain amphora types, such as Richborough 527 of Late Roman date, which have been linked to the transport of (soluble) alum (Borgard 2005), such association cannot really be proven and must remain speculative. It is almost certain that soluble alum for the textile industry did travel in the Roman period in amphora-like containers either as concentrated 'liquid' following processing or a powder, but whether it did so in a dedicated amphora type like the one just mentioned is not clear. It should be mentioned here that, although alum efflorescences are pure as they precipitate out of the steam, they need to be separated from their surrounding minerals prior to packaging and shipment. This process consists of dissolution followed by precipitation at relatively low temperatures (Photos-Jones, Hall 2014). It is almost certain that it was the enriched or near pure potassium alum or alunogen, rather than the raw material, that was shipped out of Melos and in sealed amphorae.

The alum industry of antiquity to the post-renaissance period has been aptly called by Singer (1948) the 'earliest chemical industry'. This is on account of the complexity of the mineral deposits, the different processes associated with their extraction and purification and their applications to many and specific industries. Despite substantial progress on Melos in recognising the probable sequence from raw material acquisition to finished product ready for shipping during the Roman period, there still remains much to be done in retrieving relevant archaeological evidence for each stage (Photos-Jones 2018). On the other hand, the situation in prehistory is inevitably considerably more difficult, lacking, as it does, both archaeological evidence and/or written sources. Yet, as is often noted, absence of evidence does not necessarily imply evidence of absence, and this is particularly true of the elusive astringent minerals extraction and trade in the BA.

Cyprus

Metal astringents from oxidation of copper sulphide deposits

In the eastern Mediterranean, the combined copper, iron, and zinc sulphates associated with the massive sulphide deposits of the Troodos mountain range on Cyprus were an important source of astringent minerals (Table 1). Cyprus features in Dioscorides (*De Material Medica* V) as the place of origin of four metallic astringent minerals (V.87 (*chalkos kekaumenos*), V.106 (*kyanos*), V.119 (*sory*), V.120 (*diphryges*) as well as (V.156) *amiantos* (asbestos). It is uncertain how many of those mentioned are natural and how many artificially produced in the workshop; for instance, *diphryges* (twice roasted) must have been made in the workshop, as was *chalkos kekaumenos* (burnt copper/bronze). *Amiantos*/asbestos was often confused with alum on account of its mild astringent taste (Agricola *De Re Fossilium* in Bandy, Bandy 2004). The copper mines of Cyprus appear in Theophrastus (*On Stones* 25).

By LH IIIB as Mycenaean contacts with Cyprus were reaching a peak, it is possible that the copper/iron/zinc sulphates were an offshoot of the large copper extractive activities at that time. However, the two 'industries', the metallurgical and the 'pharmaceutical', would have required a different mindset and different empirical practices of extraction and processing and it cannot be assumed that they may have started in parallel or worked in parallel with one another in the BA or indeed any other period (Konstantinou, Panayides 2013; Koucky, Steinberg 1989). Again it is a case of asking too much of the archaeological record.[3]

It is safe to assume that processing of copper/iron sulphates was in full development at the time of Galen's visit (*c.* 166 AD) to the mines at 'Soloi' in the Troodos range, and Galen himself registered his intent to assess the evidence not only in Cyprus but also on Lemnos in the NE Aegean (for the Lemnian Earth) and Syria (Galen *De Temp. Fac. Símp. Med.* 9 (Kühn XII, 171) (see translation by Wallace and Orphanides 1990). Galen was focused on what we might call today the 'pharmaceutical' industry of Cyprus rather than the copper smelting activities, assuming those were also in operation at the time of his visit to Soloi or else-

[3] At a recent meeting in Cyprus the Director of the Skouriotissa mines informed us that miners at Skouriotissa as late as the 1950s were using the copper sulphate salts to heal scratches incurred while working underground.

where in the area. We also note that similar sulphates, being products of weathering, formed at the major slag heaps at Skouriotissa on the northern flank of Troodos range; the latter date to the 4th century AD (Given et al. 2013, 266). Metallic sulphates or *vitriols* were traded from Cyprus well into the post-medieval period (Sandys 1615, 127: *Tamassus abounding with Vitriol and Verdigreafe).* The boundaries between metallurgy and 'pharmaceuticals' are blurred in the more secure Roman period, with all the benefit of literary evidence coming from the Greco-Roman scientific and medical texts. The boundaries become very elusive indeed in the earlier periods when the totality of the literary evidence, so far, can be summarised in … four words, as will be shown below.

The documentary evidence for astringent minerals in Linear B

The term *tu-ru-pte-ri-ja* appears in four Linear B tablets: two from Pylos - PY An 35 and PY Un 443 - and two small ones from Tiryns -TI X 6 - and Knossos - KN X 986. The two from Pylos are informative; An 35 records 'payment' to an individual *a-ta-ro* for an unknown amount of alum in exchange for various commodities. What is striking is the scale of the exchange involving large commodity amounts: 6 kg, 4 she-goats, 3 pieces of textile, 288 litres of wine and 384 litres of figs in one case, and 30 kg of wool and 10 pieces of textile in the other (Chadwick 1976, 157; Rougemont 2014, 356; Nakassis 2013, 99). On Un 443 the formula is similar and the payment's recipient is *ku-pi-ri-jo*; tempting as it is to see this individual, *Kuprios,* as a Cypriot, even a Cypriot trader, as Nakassis (2013, 300, n. 300) points out, he need not be a native of that island but instead someone whose family had social, economic or other links with Cyprus.[4] The point we are making is that, given that Cyprus was certainly in later periods an important producer of astringent minerals, perhaps the origin of *ku-pi-ri-jo's tu-ru-pte-ri-ya* was indeed Cyprus. In that case, these materials would have been copper/iron sulphates and not 'alum' and would have been well known to the Mycenaeans.[5]

Be that as it may, the second Pylos tablet discussed here refers to an *a-ta-ro* rather than a 'Cypriot'. The person's name has been translated as a 'blacksmith' or the 'sooty one' as a result of his name *aithaloeis* (Firth 2007, 134). This is because a connection has been built, and reasonably so, between Cypriot copper production and blacksmiths (for a detailed exposition see Firth 2007). But since alum's use (and its quantities needed) in metalworking should surely be secondary compared to its role in mordanting, tanning and perhaps medicinal as well, we are inclined to suggest that *Aithaloessa* (or *amichthaloessa*), the name given to Lemnos by Homer in the *Iliad* (24.753) owing to the purported ashes emitted by its (long extinct) volcano, Mosychlos, might be the ethnic name of the *aitholoeis* who may have arrived at Pylos to exchange 'alum'. Again the proposal is speculative.

In the course of our own work on Lemnos, we have encountered alunite-rich mineralisation and in the area of the purported extraction of Lemnian Earth limited though that was in extent (Hall, Photos-Jones 2008). Dioscorides (*Mat. Med.* V.96) and Nicander (*Theriaca* 864) refer to Lemnian *miltos* or Lemnian Earth as astringent, and we have suggested that this may have been because of its association with alunite.

Here it is relevant to note the Mycenaean presence on the island which has been recorded at Koukonisi in Moundros Bay dating to the 13th century BC (Boulotis 2013). The combination of such a presence with the alunite connection as well as *a-ta-ro* with *aitholoessa* is again tenuous and at best suggestive: could there have been a Mycenaean-period small-scale exploitation of Lemnos' alunite? Furthermore, could *a-ta-ro-aithaloeis* have been aware of the larger deposits of Lesvos which are known to have been exploited in later periods as already mentioned?

One interesting lacuna in this most puzzling of jigsaw puzzles is the apparent absence of a term equated with the mineral sulphur in the Linear B tablets. As emphasised above and illustrated in Fig. 2a, solphataric alum and sulphur often occur together. Thus, although Linear B tablets report alum (or any astringent

[4] Palmer (2003, 126-130, 139-140) discusses this issue with respect to personal names derived from ethnics outside the Aegean.

[5] The entry for στυπτηρία in the Liddell and Scott lexicon: '*astringent substances containing (a) alum or (b) ferrous sulphate*'.

mineral), why is sulphur not mentioned at all? It is highly unlikely that Mycenaeans once in the midst of a solphatara would not have noticed the pungent smell of sulphur or its yellow crystals. Could *tu-ru-pte-ri-ya* embrace sulphur as well, perhaps not grammatically, but notionally? We can only speculate, as, again, there are many questions. As a side point we mention that sulphur's purifying power receives three mentions in Homer's *Odyssey* (22.465; 23.49) in connection with the 'cleansing' of the Great Hall on Ithaca after Odysseus slaughters Penelope's suitors. But to these authors' knowledge, there is no mention of alum in the Homeric poems, thus representing the direct opposite of the Linear B tablets.

The occurrence of obsidian on two volcanic islands, Lipari in the Aeolian Islands and Melos in the Aegean, requires little introduction. This lithic, exploited as a material for the making of tools, was distributed widely during the Italian Neolithic, while Melos was the overwhelmingly dominant source of obsidian supplying most of the Aegean especially during the Early Bronze Age. In Melos, the obsidian outcrops lie within a few hours walking distance from the solphataric alum and/or alunite sources. The Loulos alunite combined with kaolinite would have made a good hemostatic for those working obsidian;[6] cuts could have been treated on the spot, as in the case of the miners in the 1950s (see footnote 4). Although the obsidian industry declined after the third millennium BC on both islands, it is unlikely that the role of alum would have been forgotten, rather its use would have continued into later phases of the BA, including the Mycenaean period, and no doubt later, since both islands were major alum producers in the Roman period.

The archaeological evidence

Mycenaean presence in the vicinity of solphataric alum

Crete, Mainland Greece and the Aegean

A hypothetical narrative takes the following course: mariners and others familiar with the coastal region of Melos were aware, at least as early as the third millennium BC, of the presence of white minerals on the island which had a variety of useful, desirable properties. They could be harvested and transported with relative ease. Mariners' visits to the island for the purpose of collection were irregular, impromptu and no doubt combined with the extraction of obsidian, the island's better known natural resource of antiquity. Access may have been via the main bay of Melos to reach the sulphurous fumaroles in caverns, such as the Kalamos promontory and the obsidian sources at Demenegaki and Sta Nychia (Fig. 3); alternatively there was coastal access to Ayia Kyriaki and Palaeochori Bays on the south east coast (Photos-Jones, Hall 2014, 161). Solphataras were also present in the north of the island (in the area of Aggereia) presently lost on account of large-scale open cast mining for bentonite (G. Christidis pers. comm.) and a Roman workshop there (possibly for alum) is currently under excavation by the Greek Archaeological Service there (P. Pantou pers. comm.).

Before the 17th century BC volcanic eruption on nearby Thera, Melos' geographical location enabled its products to reach quite readily the northern harbours of Minoan Crete, the Mycenaean mainland and no doubt elsewhere in the Aegean. After that eruption, the dynamics changed, if only temporarily. In LH IIA (late 15th century BC) the pottery evidence at Phylakopi on Melos shows increasing Mycenaean

[6] In medical terms, hemostasis is a multistep process with effect on both the blood vessels as well as the blood. In hemostasis, astringents and styptics play a different role: astringents are substances that act as vasoconstrictors since they constrict or narrow down small blood vessels such as small arterioles and capillaries. Mineral examples of vasoconstrictors are alum, aluminium chloride, zinc chloride (8-20%) and tannic acid. On the other hand, the role of styptics is to help blood coagulate (clot) which is the last stage in hemostasis. Some of the mineral examples of blood coagulants are ferric chloride and ferric sulphate (Mohan et al. 2011, 80). We can speculate that from the perspective of a Neolithic obsidian worker alum was effective in healing small cuts but much less so in stemming excessive blood flow from a major cut. On the other hand, copper sulphate would not be used as a styptic (to help in blood clotting) because it is deleterious to health (Gabriel 2012, 153). Today it is used in the context of military medicine to combat phosphorus burns (Chou et al. 2001).

presence on the island (Mountjoy 2009, 73), suggesting a resumption of supplies of minerals was at least possible. It is premature to link a direct Mycenaean connection with the alum at Ayia Kyriaki, the centre of Roman alum activity on Melos. However, an earlier, i.e. pre-Roman, horizon of activity was discovered there (Photos-Jones, Hall 2014, 136-137). As an aside to Roman alum on Melos, Raptopoulos (2005) reports a potential Cypriot connection in the form of some inscriptions on lekane handles (from Palaeochori and Ayia Kyriaki) resembling the Cypriot syllabary especially the one from the Paphos area.

Elsewhere in the Aegean Sea, solphataras are not known on pre-eruption Thera, and there are no indications of exploitation of the solphataras at the western end of Kos (in association with Kefalos Bay including Vromotopos) during the lifetime of the Minoanised (LB IA) settlement at the Seraglio (Gorogianni et al. 2016, 68) nor later during the time of Mycenaean influence (cf. Georgiadis 2008). Likewise on Nisyros, alum minerals may be associated with the fumaroles (vents) at the centre of the former volcano but an archaeological connection is lacking as prehistoric occupation concentrated on the N-N.W. coast (Melas 1988, 284). The *alunite* deposits on Lesvos have been mentioned above.

Turning to the Mainland, there are some small sources, minor by comparison with Melos that could have been visited and worked in Mycenaean times or earlier. One example is Sousaki (Fig. 1), *c.* 20 km east of the Mycenaean harbour at Corinth, where remains of former volcanic activity occur 2 km from the coast. Here at least the potential exists for the extraction of alum in the fumaroles (http://gr.geoview.info/sousaki_volcano_near_athens,877916p), although archaeological evidence of any kind at that location is lacking. Wiseman (1978, 19) mentions Sousaki but only with reference to later antiquity. Aegina may merit attention: situated not far from Palaiochora roughly midway between the major commercial centre of Kolonna of late MH-early LH date and Lazarides of similar date, which lies in the higher land in the interior (Sgouritsa 2015), is an outcrop of '*styptiria*', permits for whose extraction were given to two named individuals (*Ephemeris Kyverniseos* July 30th and October 22nd 1907, respectively). To our knowledge, this has not been confirmed by recent prospection, nor is there any known archaeological evidence in that locality and as such its relevance may remain hypothetical. On Methana LH I pottery is (very) common, much of it occurring at former MH sites; one of these is Loutra (Mee, Forbes 1997, 103), the present-day locus of hot spring activity and so, at least in principle, conditions are right there for the presence of fumaroles. In summary, the data presented here supports rather than proves the case that Mycenaeans and perhaps Minoans before them could have made use of alum in different ways since they had access to the primary source in the Aegean, Melos. But in principle the Mycenaeans had a wider range of options: besides Melos, there were small sources closer to 'home', perhaps exploited opportunistically, and, in the early and late periods, sources in the west and on Cyprus respectively.

Italy

At some point during LH I one of the first exploratory ventures westwards from the western seaboard of the Peloponnese took place, initiated by the emerging Mycenaean warrior elites. Two routes were possible, one going due west for 500 km to, say, the Straits of Messina (Fig. 1) or alternatively up the west coast of Greece to Corfu, 100 km of open sea to the first land fall in Apulia and from there to Calabria and the Straits of Messina. The former comprised an exceptional extent of open sea, the latter was longer, more circuitous and probably safer. In any case, the journeys by these two routes were undertaken in the most appropriate vessels available at the time manned by specialised personnel (Tartaron's (2013) inter-regional/inter-cultural sphere of interaction). The destinations included, significantly, the volcanic environments of the Aeolian Islands and the Bay of Naples. Finds of decorated LH I-II pottery at the former occur mostly on Lipari (Castello site) with smaller amounts on Filicudi, Salina and Stromboli (Jones et al. 2014, 50-54). Our current, preliminary investigation of these islands suggests solphataras associated with archaeological evidence at three locations: Cave di Caolino on Lipari, Calcara on Panarea and Faraglione and the Fossa, the active volcanic crater, on Vulcano (Photos-Jones et al. 2017) (here Fig. 4). To our knowledge, the only extant archaeological evidence for 'occupation' associated with early prehistoric layers is at Calcara on Panarea excavated in the late 1940s (Bernabò Brea, Cavalier 1968), but the 'settlement' cannot be considered typical of the Aeolians at the time.

In the Bay of Naples exploration of the island of Ischia and in the Phlegrean Fields on the mainland opposite would have soon established the availability there of alum minerals. At all these locations, ex-

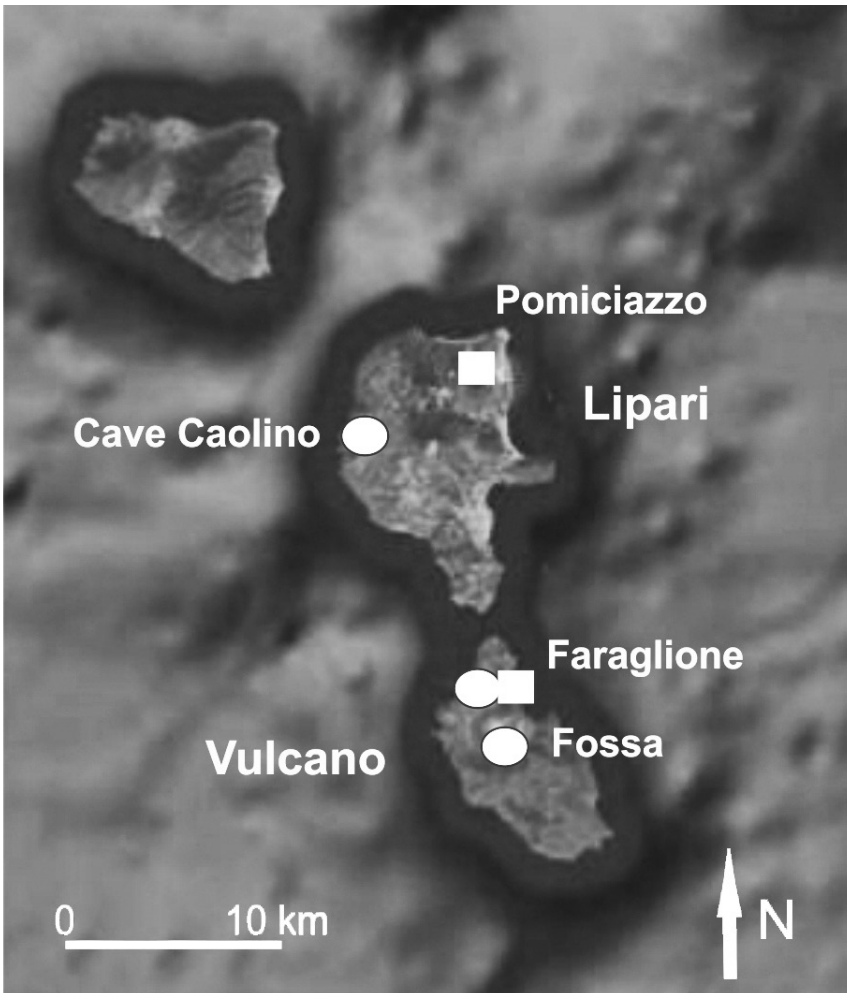

Fig. 4. Map showing solphatara locations (circle) and obsidian (square) on Lipari and Vulcano.

ploitation may have already been in place in the hands of the indigenous populations. Much decorated LH I-II pottery has been recovered from the thriving native settlements on Vivara, considerably less so on Ischia. The traditional explanation for the presence of such pottery in the West is that it represents occasional trading ventures (Jones et al. 2014, 448). In exchange for the decorated pottery (the open shapes were a product of value in its own right, and closed shapes carried a desired product such as an oil), the Mycenaean voyagers were searching for strategic raw materials such as copper and tin to meet the needs of the early Mycenaean warrior elites. More specifically, that search was perhaps facilitated by becoming part of the existing network of regional, even inter-regional exchange led by the well-placed centre at Vivara.

However, we propose a more nuanced approach to Mycenaean presence in the West, suggesting that the *first* ventures into the Tyrrhenian Sea were essentially voyages of discovery and adventure. These journeys' foremost outcome was the prestige derived from long-distance travel, and this was closely followed by the esteem gained from accessing desirable minerals present in the volcanic environments in those distant lands (Helms' (1988) 'authority of distant knowledge'). As regards the Bay of Naples, the Mycenaeans could increasingly have 'joined' the exchange network based at Vivara, but this was *not* with the goal just mentioned of gaining access to metal sources; not only is there a lack of secure archaeological evidence for early Mycenaean presence in the main metalliferous areas in Italy, notably Tuscany, but no support is forthcoming from the sourcing of copper in LH I-II bronzes using lead isotope analysis (Stos-Gale 2000). That is not to deny an absence of metallurgical activity on Vivara as the excavations at the different settlements on the island have revealed copper alloy artefacts as well as copper working debris (Giardino, Pepe 2005, 158-161); the point is that the Mycenaeans were not apparently participating in that activity.

Instead, to repeat, we argue that the Mycenaeans may have been interested in the solphataric alum available in the Aeolian Islands and the Bay of Naples. The alums occurring inland in Lazio and Tuscany, being non-solphataric, were probably not exploited until (much) later (Boisseuil 2005, 106-107, fig. 1). Another potential commodity was sulphur (La Rosa 2005, 577) that was available in the Phlegrean Fields in the Bay of Naples as well as on the south coast of Sicily near the location of the large prehistoric ritual site at Monte Grande (Castellana 1999; Vianello 2006). In any case, it is important to emphasise that the Mycenaean involvement in procuring supplies of alum and sulphur from the West was short lived and perhaps initially a consequence of the disruption caused by the Thera eruption; furthermore, those supplies need not have been large in terms of volume. By the end of the 15th century BC demand for these supplies was easily met from the sources within the Aegean.

Conclusions

This paper has put forward some hypotheses, all speculative, in an attempt to highlight some important issues hitherto relatively unexplored. Study of BA trade and exchange often becomes dominated by the search for copper and tin, while the trade in minerals and stone receives much less attention. We suggest, however, that despite the meagre evidence, trade in astringent minerals during the LBA must have relied on knowledge of the sources of these minerals and also of their 'purification' methods (which are not discussed here), however basic the latter were. This awareness of astringent minerals must have taken root very early and perhaps as an offshoot of working obsidian in the Neolithic period, both in Lipari and Melos, where the two natural resources, obsidian and alum co-exist. Astringent minerals (alum group minerals and metal sulphates) 'stem the flow of blood' (on the basis of different mechanisms but resulting in the same effect; see footnote 7), and this property would certainly not have gone unnoticed by any obsidian worker or Mycenaean trader.

Thus in discussing astringent minerals, their exploration and trade, one needs to keep in mind which industry they were intended for. The most readily available source of soluble alum for the textiles industry would have been solphataric alum, the main origin of which were Melos and the Aeolian Islands and the Bay of Naples in the west. We have identified Sousaki, in Corinthia and Aegina in the Saronic Gulf, as two potential additional candidates. Insoluble alunite may have had other applications.

The emergence of Cyprus as a major source of copper metal in the LBA must have brought into focus the associated soluble copper/iron sulphates which were also astringent and could have served instead of, or in addition to solphataric alum. We cannot know which way the trade balance tilted. White solphataric alum from Melos may have served well the mordanting industry and for whites, the copper/iron sulphates of Cyprus may have been a good source for coloured garments. Pliny gives stringent tests for the identification of traces of iron within the alunogen/potassium alum on the grounds that they would have had deleterious effects on the colouring of white fabrics (Hall, Photos-Jones 2009).

We have suggested that *ku-pi-ri-jo* in the Linear B tablet at Pylos may indeed have been the man who brought astringent materials from Cyprus, while the *a-ta-ro* may have had associations with the NE Aegean. If that were indeed the case, then they brought mineralogically different 'alums' to Pylos, but as far as the Palace was concerned they both exchanged astringent materials and appear to have been generously reimbursed.

To conclude, although this paper has exposed the many unknowns concerning the astringent minerals trade in the LBA, it is possible that study of this trade could throw light on communication networks operating at the time that differ from more traditional ones based on the procurement of metals. Fundamental to such an investigation is the archaeological record linking natural resources with artefactual evidence, as well as an understanding of the complexity of the rich variety of natural resources available to the peoples of the Bronze Age.

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